

**FRACTURES OF THE ARCHES OF THE ATLAS:
A STUDY OF THEIR CAUSATION**

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SUMMARY

The anatomical findings in 22 cases with fractures of the arches of the atlas have been correlated to the reconstructions of the events of events in the accidents. The atlas fractures due to trauma in the course of the head or neck-injuries and the results of oblique myelotomy of the neck or compression of the superior lateral part of the spinal cord. Atlas fractures against the posterior lateral surface of the posterior arch and a compression fracture of all cases were significantly associated with burst of the vertebral body of the atlas. The fractures of the atlas were predominantly on either the right or left side, although in about one-third of the cases the fractures were bilateral. The fractures of the atlas were predominantly in the middle of the arch, but the fractures of the posterior arch of the atlas were predominantly in the middle of the arch.

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SUMMARY

The anatomical findings in 22 cases with fractures of the arches of the atlas have been correlated to the reconstructions of the course of events in the accidents. The atlas fractures due to trauma to the vertex of the head or feet-buttocks were the result of oblique retroflexion of the head or compression of the anterior-lateral part of the upper cervical spine. Trauma against the forehead caused bending fractures of the posterior arch and a contributing factor in all cases were simultaneously occurring fractures of the odontoid process of the axis. Traction of the neck, most pronounced on either the right or left side, occurred in almost all victims sustaining atlas fractures due to trauma to the chin. Avulsion fractures of the inferior margin of the anterior arch were caused by lateral tilting of the head.

INTRODUCTION

As early as 1920 Jefferson claimed that atlas fractures usually arise indirectly and presented his now-classical and still-valid theories of their genesis. His conclusions rested mainly upon studies of museum specimens and cases from the literature. Further fracture mechanisms have been suggested. However, these studies have been based on single or small groups of clinical cases. No comprehensive investigation grounded on close reconstruction of the course of events and careful anatomical preparation of the neck has been found in the literature. Such an investigation is presented here.

MATERIAL AND METHOD

In approximately 250 fatalities due to accidental blunt trauma the post mortem investigation was performed with special emphasis to the cervical spine. In all cases a reconstruction of the accident was attempted. Cases in which no satisfactory reconstruction was possible and cases with extremely severe head and neck injuries were excluded as were cases with anatomical anomalies (atlas assimilation to the base of the skull, failure of fusion of the posterior arch at the midline). 22 cases with injuries involving the atlas arches remained and form the basis of this investigation.

The injuries to the surrounding soft tissues and the movement tests of the fracture fragments, fitted together after removal of the soft tissues (the way in which one fragment could be moved in relation to another) were sometimes helpful in determining the deformation of the atlas causing the fractures. Furthermore, incomplete fractures of the atlas and fractures of the base of the skull and/or axis often were useful in the interpretations.

The cases have been divided into groups according to the site of impact to the body, which was probably essential in the genesis of the fractures.

TRAUMA AGAINST THE VERTEX OF THE HEAD OR FEET-BUTTOCKS (7 cases)

Six victims had skin abrasions, lacerations and/or hematomas on the vertex of their heads. In one case there were multiple fractures both of the vertex and base of the skull and in one case multiple fractures of the vertex of the skull with one fracture running from the vertex downwards and across the base of the skull. One victim was a car occupant, whose head impacted against the deeply impressed roof of the car; one victim fell from a height landing on his head; one victim's head was struck by a heavy, falling object; one victim was a pedestrian hit by a car, and two victims were occupants thrown out of the vehicles. It could not be determined against what objects the last-mentioned three victims' heads had impacted. In the remaining seventh case the victim had jumped from a height, landing on his feet-buttocks and there were no external or internal head injuries.

The arch fractures showed a great variation in appearance but in all cases the anterior arch had a single or bilateral fracture(s).

1. Single fracture of the anterior arch (4 cases)

Case 1

The fracture of the anterior arch ran vertically through the right part of the anterior arch of the atlas and the most anterior part of its right upper joint socket. There was also an impression of the lateral-posterior part of the right upper joint surface of the axis. When the base of the skull was retroflected (hyperextended) to the right before removing the soft tissues, the fracture in the anterior arch opened, mainly in its superior part. Thus, due to the pressure of the posterior part of the right lower joint socket of the atlas, part of the right superior joint surface of the axis was impressed, the right lateral mass of the atlas was dislocated in posterior-inferior direction and stresses arose in the atlas ring, mainly between the part of the anterior arch in contact with the odontoid process of the axis and the right lateral mass.

Case 2

The fracture of the anterior arch ran vertically immediately to the left of the facet for the odontoid process of the axis. The soft tissues were avulsed from the anterior side of the anterior arch to the left of the fracture. Furthermore, there were bilateral fractures of the posterior arch in the grooves for the vertebral arteries (see Fig. 1). Due to the soft tissue injuries and the shape of the fractures, the left lateral mass could easily be dislocated and tilted in posterior direction, while the separated posterior arch could only be deflected superiorly. It can reasonably be assumed that the genesis of the anterior arch fracture was the same as in Case 1. The posterior arch fractures were probably due to the compression of the posterior arch against the neural arch of the axis, causing flexion (of the posterior arch) superiorly in relation to the lateral masses-anterior arch.



Fig. 1

Trauma against the vertex of the victim's head causing oblique retroflexion of the head (Case 2).

- a) Avulsion of the soft tissues from the anterior side of the anterior arch of the atlas to the left of the fracture. Dislocation of the left part of the atlas in posterior direction.
- b) Single fracture of the anterior arch and bilateral fractures of the posterior arch caused by dislocation and tilting of the left lateral mass in posterior-inferior direction.

Case 3

The fracture of the anterior arch ran vertically immediately to the right of the facet for the odontoid process of the axis and there was an incomplete, superiorly-posteriorly gaping fracture in the anterior arch close to the right lateral mass. The soft tissues, mainly superiorly, were lacerated around these fractures. Furthermore, there were bilateral fractures of the posterior arch in the grooves for the vertebral arteries and a small bone fragment was split off from the superior surface of the posterior arch immediately anterior and posterior to the fracture on the left side. The soft tissue injuries of the head showed that the impact hit the vertex somewhat to the right of the midline and was directed not only from above but also somewhat from anteriorly, indicating that not only was the neck compressed but also the head retroflected somewhat to the right. The cause of the atlas fractures can be assumed to be the same as in Cases 1 and 2.

Case 4

The fracture of the anterior arch ran vertically at the junction of the anterior arch and the left lateral mass and from this fracture small incomplete fractures ran to the right on both the anterior and posterior surfaces of the anterior arch. Furthermore, bilateral fractures in the grooves for the vertebral arteries were present, on the left side running obliquely in a posterior-inferior direction, on the right side obliquely in anterior-inferior direction. Due to the injuries to the surrounding soft tissues and the shape of the fracture surfaces the separated part of the posterior arch could be bent superiorly but also tilted with its right part superiorly and its left part inferiorly, indicating that it had been pressed against the posterior part of the axis, more pronounced on the left than on the right side. The genesis of the fractures of the atlas was reasonably the same as in Cases 1-3.

2. Bilateral fractures of the anterior arch (3 cases)

In all cases the fractures of the anterior arch ran vertically. They were localized at the junctions between the anterior arch and the lateral masses.

Case 5

Small bone fragments were dislocated anteriorly at the right inferior border of the separated anterior arch and immediately posterior to them there was a small impression in the most anterior part of the right lower joint surface. Furthermore, an incomplete fracture was present at the posterior surface of the anterior arch to the right of the facet for the odontoid process of the axis (see Fig. 2). Due to the shape of the fracture fragments the inferior part of the separated anterior arch could be dislocated anteriorly. Furthermore, there were bilateral fractures in the grooves for the vertebral arteries and from the fracture on the right side a small incomplete fracture ran posteriorly at the posterior surface of the posterior arch. The axis exhibited superiorly cloven transversely running bilateral fractures in the posterior part of the superior joint surfaces and foramina transversaria and furthermore a compression of the inferior part of its body. Thus, the findings indicate that due to compression of the upper cervical spine, mainly its right anterior part, the anterior part of the right upper joint surface of the axis acted like a wedge, impressing the anterior part of the right lower joint surface of the atlas and separating its anterior arch from below. The genesis of the fractures of the posterior arch is not clear but one possibility is, that due to the compression of the body of the axis, the atlas was dislocated inferiorly in relation to the separated neural arch of the axis, which was pressed against the posterior arch of the atlas.

Case 6

Besides the fractures of the anterior arch there was an impression of the right lower joint socket of the atlas especially in its anterior part. Furthermore, there was a fracture of the posterior arch immediately to the left of the midline and from this fracture an incomplete fracture ran to the right on the posterior surface of the posterior arch. Movement tests of the separated anterior arch were not quite conclusive but indicated that its inferior part had been dislocated in anterior direction. Thus, the findings indicate that compression of the upper cervical spine, most pronounced upon its right-anterior part, caused collapse of the right lower joint socket of the atlas (mainly of its anterior part) due to pressure against the anterior part of the right superior joint surface of the axis. The genesis of the fractures of the anterior arch was probably the same as in Case 5, while the fractures of the posterior arch may be due to torsional strains arising from dislocation of the right lateral mass inferiorly in relation to the left one.

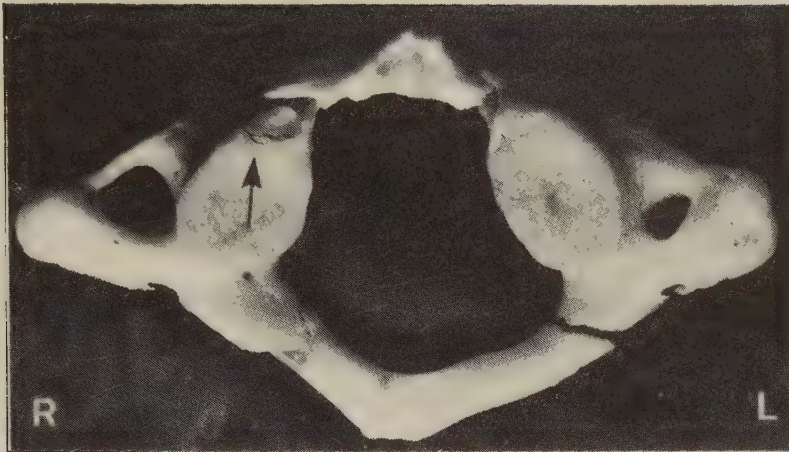


Fig. 2

Trauma against the vertex of the victim's head causing compression of the right-anterior part of the upper cervical spine (Case 5) causing bilateral fractures of the anterior and posterior arch of the atlas. Inferior view. Note the impression in the most anterior part of the right lower joint surface.

Case 7

In this case the genesis of the fractures of the anterior arch could not be determined with the help of movement tests of the fracture fragment or soft tissue injuries. However, there was also an impression of the anterior part of the right upper joint surface of the axis. Inferiorly directed pressure from the anterior part of the lower joint surface of the atlas obviously caused this impression, thus indicating that the compression in the upper part of the neck was most pronounced at its right anterior part. Therefore it seems reasonable to ascribe the splitting off of the anterior arch to the same mechanism as in Cases 5 and 6.

TRAUMA AGAINST THE FOREHEAD (4 cases)

The foreheads and anterior parts of the vertex of the heads of all the victims displayed hematomas. Two of the victims were front seat occupants in cars sustaining head-on collisions. Their heads impacted against the sunshade or windshield. One victim fell downstairs and one from a height, landing on their foreheads. In all four cases the odontoid process of the axis was fractured and could be dislocated and tilted posteriorly.

Case 8

There were bilateral fractures in the grooves for the vertebral arteries, a small impression of the anterior-inferior part of the posterior arch at the midline and a vertical fracture of the anterior arch in the facet for the odontoid process of the axis. Due to the shape of the fracture surfaces the separated part of the posterior arch could only be bent in a superior direction. Thus, the posteriorly-inferiorly directed trauma against the forehead and anterior part of the vertex of the head evidently caused compression of the neck and retroflexion of the head fracturing the odontoid process of the axis. The bilateral fractures of the posterior arch of the atlas can be attributed to bending stresses due to the anterior arch following the odontoid process in its dislocation and tilting in posterior direction. Contact with the neural arch-spinal process of the axis inhibited the posterior arch's movement and obviously caused the small impression of the posterior arch. The fracture of the anterior arch may be explained by extension of the atlas ring in transverse direction after the arousal of

the fractures of the posterior arch but it is possible that the retroflexion of the head took place somewhat obliquely creating stresses in the way suggested in Cases 1-4.

Cases 9-11

All three cases showed bilateral fractures of the posterior arch running in or immediately posterior to the grooves for the vertebral arteries. Due to the shape of the fracture fragments the separated part of the posterior arch could only be bent in a superior direction in one of the cases. The genesis of the fractures was reasonably the same as in Case 8.

TRAUMA AGAINST THE CHIN (6 cases)

All victims were car occupants whose chins exhibited lacerations and/or hematomas due to posteriorly-superiorly directed impact by parts of their own or another vehicle during straight or oblique head-on collisions. In some cases there were also fractures of the neural arch of the axis.

1. Cases with fractures of the neural arch of the axis (3 cases)

In all these cases there were non-symmetrical bilateral fractures of the neural arch of the axis. The fractures on the left side ran transversely through the posterior part of the upper joint surface and the foramen transversarium. The fractures on the right side ran in a posterior-superior direction from a point at the inferior surface situated at or posterior to the foramen transversarium. In one case the fracture on the right side reached the superior surface in a point at the level of the anterior part of the lower joint surface, while in two cases it reached a point situated posterior to the lower joint surfaces. In all three cases the soft tissues between the base of the skull and the upper part of the cervical spine were lacerated. In one case there was also an incomplete ring fracture of the base of the skull (traction-type).

Case 12

There were bilateral fractures in the grooves for the vertebral arteries and from the fracture on the right side a small incomplete fracture extended in an anterior direction on the inferior surface of the posterior arch. Movement test of the fracture fragments of the atlas excluded superior dislocation of the separated part of the posterior arch. Furthermore, the lateral-anterior part of the left superior joint surface of the axis was fractured.

Case 13

The atlas had bilateral fractures in the grooves for the vertebral arteries and an incomplete vertical fracture in the facet for the odontoid process was also present. Movement tests of the fracture fragments excluded straight superior and inferior dislocation of the separated part of the posterior arch

Case 14

The atlas showed a vertical fracture immediately to the right of the facet for the odontoid process, bilateral fractures immediately posterior to the grooves for the vertebral arteries and from the fracture on the left side a small incomplete fracture extended in an anterior direction on the inner surface of the posterior arch. Due to the soft tissue injuries and the shape of the fracture surfaces the left part of the separated segment of the posterior arch of the atlas could be only tilted superiorly.

In all three cases the trauma from an anterior-inferior direction against the chin evidently caused considerable traction in the neck. Furthermore, the non-symmetrical fractures of the neural arch of the axis indicate that also an oblique anteroflexion of the head occurred. The fractures of the atlas were probably due to traction in the upper part of the neck which was more marked on either the right or left side, but the details could not be determined.

2. Cases without fractures of the neural arch of the axis (3 cases)

Case 15

There was a vertical fracture immediately to the left of the facet for the odontoid process and an incomplete fracture at the inferior surface of the left half of the posterior arch running essentially at right angles to the arch. Furthermore, a ring fracture of the base of the skull (traction-type) was present and the right occipital condyle was avulsed. The latter finding and the incomplete fracture of the posterior arch indicate that the fractures of the atlas were due to traction of the neck which was more pronounced on the right side.

Case 16

There was a fracture of the posterior arch running from its inner surface immediately posterior to the groove for the left vertebral artery to the outer surface close to the midline. Furthermore, a ring fracture of the base of the skull (traction-type) was present. The oblique extension of the atlas fracture may indicate that the traction of the neck reasonably responsible for it was non-symmetrical.

In neither Case 15 nor Case 16 could the details of the fracture mechanism be determined.

Case 17

There were fractures in the grooves for the vertebral arteries. Furthermore, there was an avulsion of the anterior-inferior part of the body of the axis and a small rupture of the anterior longitudinal ligament at this level indicating retroflexion of the head. Judging by the relatively slight soft tissue injuries in the upper part of the neck the traction in the cervical spine was slight. It seems reasonable to consider the fractures of the atlas as due to the retroflexion of the head but the exact details of the fracture mechanism could not be determined.

TRAUMA AGAINST THE SIDE OF THE HEAD (5 cases)

In all five cases there were lacerations and hematomas on the right side of the victims' faces. Four of the victims were front seat occupants in cars hit from the right side by other cars and the victims' heads had impacted against the deformed right post of the windshield. One victim was the driver of a car sustaining a head-on collision, his face impacting against some, not ascertainable part of the car interior.

In all five cases there were incomplete marginal avulsions (incomplete fractures) of the inferior margin of the anterior arch.

Case 18

The marginal avulsion began to the right of the midline and ran in a left-superior direction. Furthermore, there was a fracture in the groove for the left vertebral artery, an incomplete fracture of the anterior side of the posterior arch near the midline and an incomplete fracture in the lateral part of the right half of the posterior arch (see Fig. 3). Hemorrhages, most pronounced on the left side, were present in the musculature lateral to the atlanto-occipital and atlanto-axial joints.

Thus, the findings indicate that the trauma to the right side of the head caused tilting of the head probably to the right giving rise to the marginal fracture of the inferior margin of the anterior arch. This fracture was reasonably due to traction, most pronounced on the left side, of the soft tissues in the anterior side of the upper part of the cervical spine. The multiple fractures of the posterior arch indicate that the atlas ring was extended in a transversal direction.

Case 19

The marginal avulsion started to the right of the midline and ran in a left-superior direction. Furthermore, there was an incomplete fracture at the inferior side of the right half of the posterior arch running approximately at right angles to the arch. Both atlanto-occipital joint capsules were lacerated with extensive hemorrhages in the surrounding soft tissues. However, the incomplete fracture of the posterior arch indicates

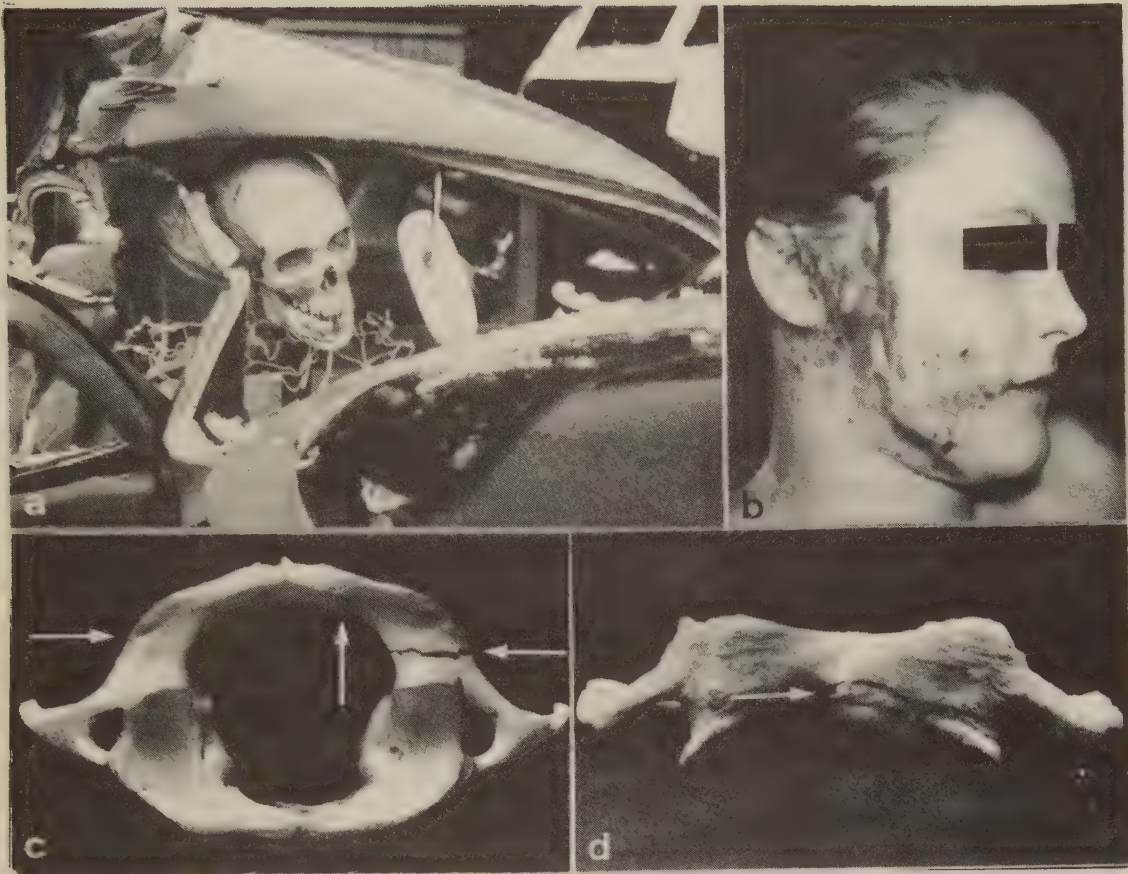


Fig. 3

Trauma against the right side of the head causing lateral tilting of the head (Case 18).

- a) Reconstruction of the impact of the head with a simple dummy.
- b) Facial injuries.
- c) Fractures of the posterior arch of the atlas (arrows) indicating extension of the atlas ring in transversal direction.
- d) Avulsion fracture of the inferior margin of the anterior arch.

superior dislocation of one lateral mass in relation to the other (i.e. lateral tilting of the head).

Case 20

The marginal avulsion started to the left of the midline and ran in a right-superior direction. Furthermore, there was an incomplete fracture at the lateral border of the right occipital condyle (i.e. the occipital condyle was partially avulsed laterally) indicating tilting of the head to the left.

Case 21

The marginal avulsion started in the facet for the odontoid process and ran in a left-superior direction. There were hemorrhages but no lacerations around the right atlanto-occipital joint indicating that the head tilted to the left.

Case 22

The marginal avulsion started to the left of the midline and ran in a right-superior direction. Furthermore, a laceration of the dura mater at the left side of the foramen magnum, avulsion of the left lower joint socket of the atlas and lacerations of the joint capsules of the atlanto-occipital and atlanto-axial joints on the left side were found indicating that the head tilted to the right.

The findings indicate that the marginal avulsions in Cases 19-22 arose in essentially the same way as in Case 18.

DISCUSSION

I TRAUMA AGAINST THE VERTEX OF THE HEAD OR FEET-BUTTOCKS

Jefferson's classical theory concerning the genesis of the atlas fractures is that axial compression of the cervical spine creates a wedge effect, i.e. compression of the atlas between the skull and the axis causes dislocation of its lateral masses in lateral direction due to the inclination of the joint surfaces towards the occipital condyles and towards the superior joints of the axis (Jefferson, 1920, 1927; Plaut, 1938; Hatchette, 1941; Hinchey et al, 1945; Graubard et al, 1949; Rogers, 1957; Hipp et al, 1963; Ruge, 1969; Sherk et al, 1970; Braakman et al, 1971; Rijsbosch, 1971; Shapiro et al, 1973; Sherk, 1975; Barker et al, 1976). That the head is hit by a semicompressible object and that the neck is fixed in a straight position are considered to be prerequisites for fractures of the atlas arising in this way (Jefferson, 1927; Plaut, 1938; Sherk et al, 1970; Barker et al, 1976).

In the material presented here there are several cases in which the trauma was directed against the vertex of the victim's head or his feet-buttocks and thus at first glance it seemed reasonable to suppose that the atlas fractures arose due to the mechanism suggested by Jefferson. However, closer investigation revealed that other mechanisms were essential in the genesis of the fractures since the compression of the neck did not take place in a straight superior-inferior direction:

1. Oblique retroflexion of the head combined with compression of the neck

In this situation the posterior part of one occipital condyle - due to the posteriorly-superiorly directed inclination of the posterior parts of the surfaces of the atlanto-occipital joints - exerts pressure on the posterior part of the upper joint socket of the atlas in posterior-inferior direction and tends to dislocate and tilt the lateral mass on the same side in posterior direction. The shape of the atlanto-axial joints is not suited to inhibit such a dislocation of the atlas on the axis. Instead, the movement

is probably inhibited by the pressure of the odontoid process of the axis against the posterior surface of the anterior arch of the atlas. Thus, strains and stresses arise in the anterior arch between the part in contact with the odontoid process and the lateral mass on the most effected side. During the retroflexion of the head and the above-mentioned movement of one lateral mass of the atlas, the posterior arch impact against the neural arch of the axis creates bending stresses and possibly fractures, primarily in the grooves for the vertebral arteries. These grooves are considered the weak areas of the posterior arch (Jefferson, 1920, 1927; Ruge, 1969; Sherk et al, 1970; Rijsbosch, 1971).

2. Compression of the upper part of the neck, most pronounced anteriorly and somewhat laterally

Under these circumstances the anterior margin of the superior joint surface of the axis on the most affected side obviously can act like a wedge, splitting off and dislocating anteriorly the anterior arch from below.

Our findings indicate that the fractures in the posterior arch observed in some of these cases may be considered to be due to torsional strains and impact from a separated neural arch of the axis. A wedge effect in the way suggested by Jefferson after the stability of the atlas ring has been lost due to the injuries of the anterior arch may also be of importance. However, it is worth pointing out that in the material presented here there is no case with fractures of the atlas probably due to pure wedge-effect, that is, caused entirely by compression of the neck. This finding indicates that atlas fractures originating in this way either are much more rare than usually thought or are very seldom combined with fatal injuries to the cervical spinal cord.

II TRAUMA AGAINST THE FOREHEAD

The second fracture mechanism suggested by Jefferson is fracture of the posterior arch of the atlas by a leverlike action due to a crush between the occipital bone and neural arch of the axis with the head in full extension (retroflexion) (Jefferson, 1920; Plaut, 1938; Hatchette, 1941; Graubard et al, 1949; Hipp et al, 1963; Sherk et al, 1970; von Torklus et al, 1970; Shapiro et al, 1973; Shrago, 1973). It is well-known that fractures of the

atlas are often combined with fractures of the odontoid process of the axis (Jefferson, 1920; Hinchey et al, 1945; Rogers, 1957; Ruge, 1969; Sherk et al, 1970; Braakman et al, 1971; Barker et al, 1976). The findings in this investigation clearly show that a fracture of the odontoid process due to a trauma directed posteriorly-inferiorly against the victim's forehead, contributes greatly to fractures of the atlas. This is obviously due to the fixation of the anterior arch to the odontoid process.

III TRAUMA AGAINST THE CHIN

In the material presented here there is no case with fractures of the atlas combined with bilateral fractures of the neural arch of the axis caused by retroflexion of the head and compression of the neck as described by Cornish (1968), Rijsbosch (1971) and Brashear et al (1975). It has recently been found (Sköld, 1977 b) that bilateral symmetrical fractures of the neural arch of the axis usually are due to anteroflexion (forward flexion) of the head in combination with traction or compression of the neck. In such cases fractures of the atlas have not been observed by the present author except in one in which the body of the axis was compressed (Case nr 5). In contrary, in all three cases observed with asymmetrical fractures of the neural arch of the axis - probably due to oblique anteroflexion of the head (Sköld, 1977 a) - there were also fractures of the atlas. These findings indicate that when an anteroflexion of the head causing fractures of the neural arch of the axis takes place in the sagittal plane, the atlas follows the odontoid process and body of the axis separated from its neural arch. This is reasonably due to the soft tissue connections between the base of the skull and the posterior arch of the atlas being stronger and more tense than those between the posterior arch of the atlas and the neural arch of the axis. If however, the simultaneous occurring traction of the neck is more pronounced on either the right or left side of the neck due to anteroflexion of the head in oblique direction, there evidently arise considerable strains and stresses in the atlas probably via the soft tissue connections between the base of the skull, atlas and axis. However, the details are not yet known.

Also, in some cases with impact from an inferiorly-anteriorly direction against the lower part of the face and lacking fractures of the neural arch of the axis the anatomical findings indicated that the traction of the neck had been more pronounced on either the right or left side. In this context it is worth

mentioning that Schmitt et al (1977) recently published a case with multiple fractures of the atlas, considered due to a whiplash mechanism, however, in oblique direction.

In the material presented here there is only one case with isolated bilateral fractures of the posterior arch of the atlas probably due to impact against the chin causing retroflexion of the head in the sagittal plane. The exact fracture mechanism in such cases is not determined. However, one conceivable possibility is that in retroflexion of the head the posterior part of the occipital condyles exert pressure against the posterior part of the joint sockets of the superior atlanto joints resulting in a posteriorly-inferiorly directed tilting of the lateral masses of the atlas around the posterior border of the superior joint surfaces of the axis. This movement is probably counteracted posteriorly by contact between the posterior arch of the atlas and the neural arch of the axis creating bending stresses in the anterior part of the posterior arch.

IV TRAUMA AGAINST THE SIDE OF THE HEAD

Avulsion fractures of the inferior margin of the anterior arch of the atlas observed in several cases in the present material were seen by Hatchette (1941) in one case and are reasonably identical with the horizontal fractures of the anterior arches described by von Torklus et al (1970) and Stewart et al (1977) who considered them to arise during retroflexion of the head and to be caused by the anterior border of a fractured odontoid process or the anterior longitudinal ligament and anterior atlanto-axial membrane (von Torklus et al, 1970), the odontoid process or the superior oblique portion of the longus colli muscles and the anterior longitudinal ligament (Stewart et al, 1977). Our findings support the assumption that these fractures are caused by traction of the muscles and ligaments inserting at the anterior arch but also indicate that lateral tilting of the head is essential in their genesis. The last-mentioned finding indicates that the pull at the inferior border of the anterior arch of the atlas must be directed obliquely in inferior direction to cause avulsion fractures along its inferior margin. Retroflexion of the head in straight sagittal direction usually causes other injuries of the cervical spine.

In one of these cases the atlas ring had obviously been extended in transverse direction. This may be due to dislocation of the head and atlas due to the trauma to the side of the head, but also extreme inclination of the head may dislocate the atlas laterally in relation to the axis due to wedge effect. The dislocation of the atlas is inhibited, probably mainly by contact between the odontoid process and the lateral mass of the atlas on the contralateral side, resulting in a transverse extension of the atlas ring.

Finally, it is worth mentioning that fractures of the anterior arch of the atlas by means of the odontoid process of the axis, the third fracture mechanism suggested by Jefferson, have not been observed in the investigated material. This finding supports the general opinion that a sufficient pressure of the odontoid process against the anterior arch primarily causes fracture of the odontoid process and not of the anterior arch.

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